PATHOPHYSIOLOGY OF AMBLYOPIA: AN INTRODUCTION TO PLEOPTICS*

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THERE is no question that some cases of amblyopia are amenable to treatment by methods which one may be inclined to call old-fashioned—by the wearing of a proper refractive correction, and by occlusion of the better eye, with some kind of planned eye-exercises sometimes added for good measure. The term *amblyopia ex anopsia* roughly means poor vision due to non-use, and if non-use is the only cause of the poor vision then putting the eye to use should be *the method* of curing the condition. This, unfortunately, is not always the case. There have been instances, and not infrequent ones, in the experience of all of us in which an amblyopic eye did not react with improvement of visual acuity to the procedures just mentioned, especially the occlusion of the better eye. Obviously, the pathogenesis of amblyopia is not that simple, and neither are the principles upon which treatment should be based.

In recent years, some of these cases—so far seemingly unimprovable—have reacted quite remarkably to certain newer eye exercise techniques, now known as *pleoptics*. These are the techniques about which we intend to report to you tonight. The clinical procedures, the primary aim of which is the "exercising" of eyes not properly coordinated for effective binocular vision were, up to now, collectively labeled "orthoptics"—the name indicating that "straight vision" in the cross-eyed has been their main objective. "Pleoptics" means something like "fuller vision". Better vision, fuller visual acuity in the amblyopic eye should, in fact, be the first and more important goal of eye exercises. Straight vision (actually meaning binocular vision) is hardly ever achieved if one of the two eyes continues to have poor vision. Fuller vision in the two eyes is a prerequisite of straight vision. Orthoptic exercises, exercises to develop straight vision, binocular cooperation,

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have given disappointing results in so many cases that orthoptics has for quite some years acquired a degree of disrepute. Many of us believe that this will change in the future. The more active pleoptic methods aiming at the redress of amblyopia seem to offer new hope. If amblyopia can really be cured in a majority of those afflicted, then exercises directed at the establishment of binocular vision may once more regain the respectability they seem to have lost.

Amblyopia ex anopsia is, more often than not, associated with anisometropia, especially aniso-hypermetropia (unequal hypermetropia in the two eyes), and the usually poorer visual acuity of the more hypermetropic eye is in these cases easily explicable.

Hypermetropic eyes need to accommodate to see well at any desired distance. The amount of the accommodation actually exerted in a given instance depends on the magnitude of the refractive error of the *less* hypermetropic eye, if the refractive error in the two eyes is not the same. The more hypermetropic eye cannot do better than follow suit. It does not, therefore, accommodate sufficiently and, as a consequence, only unsharp images are formed on its retina. Since sharp contours are the prerequisite of good vision, the information offered the brain by the more hypermetropic eye will generally be of lesser use. The eye will easily fall into disuse. And since visual acuity in the growing infant and child develops gradually, by the proper engagement of both sensory and motor factors, one will understand that in such eyes it will not reach maturity value. This is the condition, probably, to which Chavasse's term "amblyopia of arrest" can properly be applied, though "amblyopia from arrested development" is what is actually meant.[1] An eye that has never had the chance to see well does not see well.

The wearing of an accurate refractive correction will eliminate the original disadvantage by improving the quality of the retinal image. And if the "bad habit" of non-use has not yet become unconditioned in its fixity, then the chances are good that this and temporary occlusion of the better eye may cure the amblyopia. If the eyes are straight, if conditions for binocular cooperation are favorable, then the gain may even become permanent; fuller vision with straight vision, even binocular vision has often been achieved in such cases without the help of any other procedure.

The usefulness and the usableness of the visual information offered by the more hypermetropic eye decreases even further when strabismus complicates matters. This occurs especially in such cases of aniso-hypermetropia in which the less hypermetropic of the two eyes is also *considerably* hypermetropic.

Hypermetropia calls for constant accommodative effort, even for distance vision (and more so, of course, for near vision), and accommodative effort invokes convergence. Since fixation must be accomplished by the better eye, this eye will—though accommodating—not converge. The poorer eye, the more hypermetropic eye, having no sharp retinal image to work with, will have no incentive to fixate. Thus, it will readily submit to the convergence impulse until finally convergent posture becomes a constant feature of this, the more hypermetropic, eye.

While this is a rather easily understandable mechanism to explain the development of unilateral convergent strabismus, it must be mentioned that such deviation also occurs with little difference in hypermetropia, or even without any refraction anomaly to explain it. This is certainly not the appropriate occasion to discuss the other possible etiologic factors that may cause unilateral strabismus. Suffice it to say that the sensory and motor consequences of unilateral (non-alternating) convergent strabismus will be the same whatever its cause, and for the sake of simplifying my analysis of these consequences I shall restrict myself to a discussion of strabismus with aniso-hypermetropia.

It is in the nature of things that in this case it is the more hypermetropic eye that deviates. The object of momentary attention, the object of fixation will produce a desirably sharp image in the fovea of the sound eye only. However, the fovea of the squinting eye will not only receive an unsharp image, but this image will not be that of the object of interest, of the fixation object, altogether. The image of some other object of no momentary attention value (possibly of no attention value at all) will fall on the fovea of the deviating eye. The acuity of vision in this eye will not only not develop to its normal power, it will actually deteriorate from its level of accomplishment, since not even the unsharp image of the object of attention now falls upon its fovea. "Amblyopia of extinction", another of those eminently expressive terms by Chavasse, characterizes this pathologic process very well.

Since under normal conditions the foveas of the two eyes are so-called corresponding retinal points (by which is meant that whatever they look at appears to be in one and the same direction), squinters actually ought to see two non-identical, even non-related objects in the same place, in the same direction. Von Kries attached the name "confusion" to this phenomenon, and there is hardly any word that could better describe it. However, confusion is only part of the picture. While the straight eye fixates some object of momentary attention, the image of the same object falls upon a more peripheral area of the squinting eye, upon a retinal area which does not correspond with the fovea of the fixing eye. The outcome is, or ought to be, diplopia, the seeing of one and the same object twice, in two different directions.

Confusion and diplopia, however, actually occur in cases of paralytic strabismus only, in cases in which some sudden obstacle arises in the path of the up-to-then normal binocular coordination. A child with strabismus dating from an early age will very seldom complain about confusion and never about diplopia. The abnormal conditions lead to an abnormal type of conditioning. They make adaptive mechanisms operative which eliminate both the confusion and the diplopia. But the price is more than the amblyopia—whatever the adaptive value of amblyopia. Both, the fovea of the deviating eye (upon which the image of some uninteresting, non-fixated background detail is consistently falling), and that other extramacular area (upon which the image of the object of interest *happens* to fall), acquire the "bad" habit not to contribute to vision. We speak of functional scotomas, of suppression areas in the deviating eye.

It would lead too far afield to explain how the eye and the brain accomplish this. I can only suggest that suppression is a kind of extreme case of an essentially normal, physiologic, and ubiquitous adaptive mechanism, viz., retinal rivalry. Usual retinal rivalry means a kind of see-saw process. If two equally seeing eyes are presented with equally impressive but non-fusible details in a stereoscope, then only one or the other set of contours will be seen at any moment of time, in an alternating manner. In the case of poorer vision in one of the two eyes, or marked dominance of one eye, the contours seen by one eye will be domineering and the rhythm of alternation will favor the better or the dominant eye. Whatever this eye sees will be seen through a greater fraction of each see-saw circle.

In the case of equally good vision in both eyes and alternating strabismus rivalry turns into suppression in one eye as long as the other eye fixates. This is easily accomplished since only the fixating fovea turns at the object of attention with its usually conspicuous contour details, while the other fovea covers an area of only background interest.

In the case of unilateral strabismus the contribution to vision from the fixating eye will almost constantly prevail. This will be especially true in the case of aniso-hypermetropia where only the image in this eye is sharp. The other eye will hardly ever have any chance and it will finally get used to not being given a chance.

The habit not to contribute to foveal vision is the more conspicuous of the just analyzed "bad" habits. Actually, they are desirable habits since they eliminate the above described disturbing, hence undesirable, sensory consequences of strabismus. The desirability of the habit of foveal suppression is obvious as long as the fovea of the squinting eye is non-contributory to vision only while both eyes are open. Unfortunately, a conditioned response can become fixed beyond the limit up to which its adaptive value is obvious. Thus, this habit can become so much ingrained that the fovea remains non-contributory even when the other eye is closed or lost and there is no danger of confusion. This is the condition we call *amblyopia ex anopsia.*

The non-contributing habit of the second area is not that easily detectable. Our usual clinical methods of functional analysis are centered around the performance of the fovea and we seldom bother with the complex arrangements needed to prove that this extra-foveal area also is an area of scotoma, at least as long as both eyes are open.

However, this particular retinal area in the deviating eye, the area which is usually "covered" by the image of the object of momentary attention (the Germans have given it the rather descriptive name *Deckstelle*), not only learns *not* to cause trouble by diplopia. Strabismus causes the adaptive reassessment of another of the functions of the deviating eye: it breaks down its natural sighting mechanism. This mechanism normally tends to aim the area of best vision, the fovea, at the object of interest once we have chosen an object of interest, and also tends to keep the fovea "covering" this object as soon as the motor apparatus succeeds in turning the eye into the proper position.

By being constantly conditioned into its inferior way of seeing, the deviating eye finally gets into the habit of sighting the object of interest with the wrong retinal area, not only while both eyes are open and seemingly cooperate in their lopsided manner, but also when the good eye is occluded. The poor eye will (by force of habit, so to speak) not aim its fovea toward the object of interest, even when it is conducting the business of vision all by itself. Fixation (as we call this motor process) will have become eccentric. As is well known, the structure of the retina is such that only the fovea has the necessary equipment for good vision. Eccentric areas do not. Thus, *the squinter's eye with an area not suited for good vision will aim toward the point he wants to see better.* He may even see best a point, a detail, that he does not actually fixate and has not actually planned to fixate.

This conflict, a kind of monocular confusion between what is meant to be seen best and what is actually best seen, is quite characteristic of many cases of amblyopia with strabismus when only the squinting eye is used for vision. It probably offers a simple explanation of the bewildering performance of the amblyopic eye as it is facing a line of letters on a Snellen chart. I do not think that such concepts as cortical *vs.* angular visual acuity are needed to explain it.

As I have just indicated, the job of the fixation mechanism is a twofold one. It must, first of all, bring the fovea to bear upon the object of interest once this has been chosen. (We call this oculo-rotation "voluntary" since the object of interest is of our own choosing; thus, the eye moves where we want it to.) It also must keep the image of the object of interest glued to the fovea once sighting it has been accomplished. The eye* becomes momentarily immobilized, fixed, by the properly apportioned simultaneous contraction of the respective antagonists. (We call the mechanism which accomplishes this a "reflex" mechanism since we cannot help but re-fixate an object of interest in case its image wears off our fovea, as long as we keep it our object of interest.) Since the fixated object is best seen, it naturally becomes the center of reference relative to which other objects are localized (arrange themselves in our visual world). If the image of some object falls upon a retinal area to the right of the fovea, the originator object of this image must be to the left of the momentarily fixated object, and our eye would have to turn to the left should we decide to make it the object of our attention. Physiologists speak of this aspect of space perception as "relative" spatial localization, as it involves the localization of one seen object relative to another seen object.

There is no point continuing the heated discussion of many decades about the learned or innate character of relative localization. Obviously

* I speak about "the eye" in the singular, although it is always both eyes that have turned into some conjugated position. However, I want to avoid any allusion to binocular visual or motor mechanisms, at least for the moment, and deal separately first with the normally fixating, and later with the eccentrically fixating eye of the squinter.

the structures which enable the eye as a camera to receive images in different loci of the retina, of objects which are in different loci of space, are innate. The structures which carry the visual message from *each* right retinal hemisphere into the right visual cortex are also innate. And the structures that mediate the oculo-rotary impulse to the proper extra-ocular muscles are also innate. In this sense, then, relative localization is innate.

If the object of interest happens to be far to one side of our body, then the fixation mechanism brings the eye into a position it can maintain only with difficulty. The balance of antagonistic muscles is only an apparent one. If the fixated object is, say, to the right of me, then the external rectus muscle of my right eye must contract more than the internal rectus. We turn our head in the direction of the fixation object rather than maintain prolonged fixation out of the corner of our eyes. We even prefer to turn our whole body into line with what we anticipate will become the object of more than momentary interest. We turn our chair toward the television screen. We would hardly sit happily through a Wagnerian opera performance if we could only see the stage with our neck twisted. Our extraocular muscles as well as our neck muscles—not to mention the endolymph in our inner ears—prefer a position of real balance. In the case of the eyes we call this position the "primary" ocular position. It is the particular stance which, under ideal circumstances, permits the eye to be straight in relation to its socket, level to the horizon and in line with the sagittal plane of the head.

This being the case, a particular innervation pattern and the particular pattern of feed-back information—proprioception, if you wish—of a particular ocular position becomes an important and integral part of our spatial orientation, of directionalization *relative to ourselves*. Whatever image falls upon the fovea under these conditions, is not only best seen, is not only the center of the "relative" localization of the less well seen peripheral objects relative to the best seen one; it is also, of necessity, the image of an object straight ahead of us. Only thus, only secondarily, only *via* motor-sensory feedback information, can visual information contribute to orientation, to what the physiologists call "absolute" localization. The presence of an image on the fovea does not in itself furnish this information. The fovea does not possess a local sign, an "absolute" directional value "straight ahead". An object—and I shall return to this point once more—is not seen straight ahead because its image falls on the fovea. An object, while the center of visual interest, need not be straight ahead of our body at the same time. An object, while best seen, can be anywhere in visible space. And to comfort the philosophically minded, we may add simply and categorically: An object is seen straight ahead of us because *it is straight ahead* of us.

Under pathologic conditions, also in experimental situations (for instance, in the Bárány chair), these orientational clues may give false information. The example that should be of some interest in this connection is, again, the case of a recent paralytic strabismus. Here a particular pattern of innervation will not correspond with some particular ocular stance. Orientation, perception of particular spatial relations between the self and the surround, will be disturbed. We call the phenomenon dizziness or disorientation.

The fact that extraocular muscular innervation patterns greatly influence absolute localization, localization of objects relative to the self, is the basis of the so-called past-pointing test, well known to clinicians: an object slightly to the right of an observer is judged by him as being *far* to the right, if this observer happens to have a paretic right external rectus muscle and tends to turn his right eye toward that object.

In concomitant strabismus there is no disorientation. The deviating eye adapts itself to changed conditions and modifies its contribution to spatial orientation. We have already indicated how this eye gets used to sighting the object of interest—at least to "covering" it—with an extramacular area. We have seen how it gets used to turning this area toward any new object of interest, thus presenting the phenomenon of a new, anomalous, ancillary motor correspondence. When we speak of "concomitant" squint, we actually describe this characteristic ancillary motor behavior of the deviating eye. We can now add that the extraocular muscles of the deviating eye finally adopt a particular position as best balanced—not that position in which the eye is straight and appears straight to others, but the position which it usually occupies when the other, the fixating eye, is straight. The particular innervational and proprioceptive patterns from this particular ocular stance convey the information *to the squinter* that this eye *too* is straight. The squinter *is not* subjectively conscious of the fact that he squints.

Once this adaptive change has occurred, there has come into existence a new quasi-harmonious relationship between the two eyes. To the acquired anomalous motor correspondence a new sensory factor has been added. The anomalous motor correspondence turns the fovea of the sound eye and the false fovea of the deviating eye upon the object of momentary interest. It does this primarily to avoid diplopia. (Those reports of fusion, binocular vision, even depth perception accomplished through this new anomalous cooperation all belong in the realm of wishful imagination.) The new sensory correspondence, the modified extraocular feed-back mechanism, however, serves a constructive purpose.

Let me repeat: when a normally fixating eye is in its best balanced position, then the image that occupies its fovea signifies an object straight ahead. The squinter's deviating eye confirms, in the end, this localization: the image impressed upon its false fovea at the same time eventually also signifies an object straight ahead.

A squinter's deviating eye is in its best balanced position when its false fovea, not its anatomical fovea, aims straight ahead.

Once the forward bearing position of the false fovea of the deviating eye has become the best balanced, the "primary" position of this eye even when the other eye is covered, the false position of the deviating eye is hard to change thereafter. A new type of quasi-binocular integration has come into being, a faulty one, but one which within its own limits is effective and causes no discomfort, embarassment or strain. I am not sure if these cases are not best left alone. Only further research by another generation of pleoptics enthusiasts will be able to tell if these cases can also be re-educated.

It is in the cases of amblyopia with the earlier described response habit of eccentric fixation in which we can now hope that the new methods of examination and treatment will give us an added chance. The most important of the new diagnostic procedures is the study of the fixation pattern of the amblyopic eye. With the help of a suitable ophthalmoscope one projects a sharp image of some simple target upon the retina. The most popular of the projected targets is Cüppers' star. The examiner looks at the image of this target projected on the examined retina and, at the same time, asks the person he examines to fixate the star. For me it is always a unique experience to see on the fundus of an eye that I am examining the very optical image which gives to this eye its chance to see. I see the star on the retina; the subject, of course, sees it "in front". Moreover, the examiner has the unique opportunity of observing the very act of intentional seeing, the sighting reaction, the mode of the sensory motor response involved in fixation.

If fixation is centric, if intentional seeing directs the image of the object to fall on the fovea, then all can still be well even if the eye is amblyopic. As I have already mentioned, treatment in such a case need only consist of reinforcement along the well established lines of orthoptic management with occlusion of the better eye.

It now seems to be a matter of general agreement that the classical type of treatment of amblyopia is of no use in the case of eccentric fixation. In fact, it is now generally believed that the classical treatment, the occlusion of the better eye, forces the poorer eye to continue with its mode of fixation, that, in other words, the old ways of therapy have reinforced rather than eliminated eccentric fixation. It has therefore become the newly accepted procedure to occlude the poor eye rather than the good one as the first step toward changing the habit of eccentric fixation.

The next steps in therapy are still in the stage of experimentation, and I can only give you the bare outline of the methods suggested by the two principal exponents of the new active treatment of *amblyopia ex anopsia*, and especially of eccentric fixation.

Bangerter,[2] the man who introduced the new word *pleoptics* into our medical vernacular, believes in awakening the dormant capabilities of the fovea by direct stimulation. The causes of eccentric fixation are not his essential concern. He believes that eccentric fixation is purely a matter of physiologic pragmatism. As the retinal fovea, even the macula, becomes inhibited, a relative central scotoma ensues with lowered central visual acuity (as already mentioned, *amblyopia ex anopsia* is but another name to designate this particular central scotoma) and the eye turns an eccentric area toward the object of attention when fixation is desirable, simply because this eccentric area has, at the moment, best vision. This area of facultative best vision needs to be knocked out, so to speak, since the eye has become used to aiming with this area at the object of momentary interest. Bangerter uses a strong light under direct observation of the eyeground to "dazzle" this area into lessened usefulness, and immediately following this stimulates the real fovea with intermittent light pulses before the false fovea has a chance to recover from its dazzled state.

Bangerter's reported results are good, his techniques are simple in principle. It is, I think, mainly the complexity and the enormous price of some of his instruments that make it difficult for his method to gain more general acceptance. It is certainly the principal reason why I was unable to gather any personal experience in connection with it. Besides, a new technique has developed in Germany, based on some interesting ideas of Cüppers, a neurophysiologist turned ophthalmic researcher, a method which, at the moment, seems to be in ascendancy, though the discrepancies between the two methods are less than at first seemed apparent.

Cüppers'[3] explanation of eccentric fixation is based on the concepts I have just presented about the squinter's vision.

Let me repeat: if an object is straight ahead and the object is of interest and if a squinter has developed the type of anomalous motor and sensory correspondence I have described, then this squinter turns the fovea of his sound eye and a rather well defined extrafoveal area of his squinting eye toward this object. He sees the object best because he looks at it with the fovea of the fixating eye. He judges it to be "straight-ahead" because it *is* straight ahead and because the innervational pattern and the extraocular muscular feed-back information confirm this. At the same time, his deviating eye covers the object of interest with an extrafoveal area. Innervational pattern and feed-back information from this actually deviating eye *falsely* signal the straightness of this eye and thus *correctly* confirm the straightness of what is covered with a false fovea. If, per chance, the image of some object falls on the real fovea of the deviating eye, then the object is sensed as being in some other absolute direction—not straight ahead. This is the habit—the newly conditioned reflex, as it were—of absolute localization which Cüppers tries to break. His treatment methods are not directed at the amblyopia as such, but at the faulty absolute localization first of all.

These sensory disturbances can most impressively be demonstrated with the after-image technique. Ophthalmologists have for many decades used after-images to test the nature of the binocular sensory motor coordination in squinters. The subjective after-effect of any intensive stimulation of the fovea of an eye must, by the very nature of things, appear in line with the fovea. A normal eye, with a normal sighting mechanism, sets its fovea in line with the object of momentary interest. Thus, any point fixated with a normal eye is "covered" by the after-image, if the fovea has been stimulated prior to the fixation. If a deviating eye has developed the habit of sighting with that often mentioned false fovea (its new fovea of fixation, not its fovea of best vision) then whatever after-image has been impressed upon its anatomical fovea (its fovea of real or potentially best vision) will not appear in line with directed attention. Brock and Givner[4] have demonstrated this fact with their so-called after-image transfer test.

Cüppers' brilliant idea was to make the squinter conscious of this discrepancy and to train him to turn a foveally impressed after-image upon the detail of suggested attention, to "cover" this detail with the after-image, although in the beginning this will give him the feeling that he is looking sideways from the object he wants to look at. He will soon be rewarded by noticing that he sees this object better. Another of Cüppers' methods (and he too is almost overzealous in inventing newer and newer instruments) utilizes the recognition of a macular entoptic phenomenon—called Haidinger's brushes—as an indicator of the position and direction of the true fovea. By gradually learning to place the fovea of his deviating eye in line with what he should be looking at (first guided by the after-image, or the Haidinger phenomenon, later even without it), the squinter is rewarded by better vision. His sighting rectifies itself. His amblyopia cures itself. Possibly even his false orientation gives way. There are, of course, some complications and still many failures.

Be this as it may, Cüppers has initiated an extraordinary method of treatment, a method by which foveal fixation can be re-established as a learned function. Whatever the value of his theory, his method works. The treatment of *amblyopia ex anopsia* with the help of Cüppers' entoptic image technique is, in my opinion, one of the great therapeutic successes of ophthalmology in our present days.

REFERENCES

1. Chavasse, F. B. *Worth's Squint, or the Binocular Reflexes, and the Treatment of Strabismus.* Philadelphia, The Blakiston Company, 1939.
2. Bangerter, A. *Amblyopiebehandlung, 2. ed.,* Basel and New York, S. Karger, 1955.
3. Cüppers, C. Moderne Schielbehandlung. *Klin. Mbl. Augenheilk., 129*:579-604, 1956.
4. Brock, F. W. and Givner, I. Fixation anomalies in amblyopia, *Arch. Ophthal. (Chicago) 47*:775-86, 1952.